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EFFECT OF T6 HEAT TREATMENT ON HARDNESS WEAR AND FATIGUE BEHAVIOUR OF NICKEL COATED CARBON FIBER REINFORCED AL-7079 MMC

ANANTHA KRISHNA SOMAYAJI[1] & NARASIMHA MARAKALA[2]

[1]*Associate Professor, Department of Mechanical Engineering, NMAM Institute of Technology, Nitte, India*

[2]*Professor, Department of Mechanical Engineering, NMAM Institute of Technology, Nitte, India*

ABSTRACT

Aluminum metal matrix composites are preferred over other conventional materials in the field of aerospace, marine and automotive applications due to their improved tribological and mechanical properties and increased strength to weight ratio. As reinforcement carbon fiber is a very promising material and carbon fibers increase the wear resistance and also reduce the friction coefficient of AMCs. Al 7079 consists of zinc as the major alloying element which has good fatigue strength and is strong, but has average machinability. But T6 heat treatment improves its machinability and also increases its hardness. This paper presents electroless nickel coating to coat the carbon fibers with nickel. These coated fibers are then mixed with aluminium 7079 alloy by stir casting technique. The casted AMC was subjected to T6 heat treatment and hardness, wear and fatigue property of the composite was evaluated.

KEYWORDS: Aluminium Matrix Composites, Electroless Coating, Stir Casting & PAN Carbon Fiber

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Original Article

1. INTRODUCTION

Metal matrix composites (MMCs) are gaining vital importance in several areas due to its improved tribological and mechanical properties when compared with primary alloys, especially in several applications where stiffness to weight and strength to weight ratios are of great importance as in automobile, aerospace and defence applications [1-3]. Aluminium matrix composites (AMCs) is most commonly used in various engineering fields such as aerospace, marine and automobileparts such as brake drum, engine piston and cylinder liner etc. The most commonly used reinforcement materials for aluminium matrix composites (AMCs) are silicon carbide, alumina, copper and various fibers [4].

Carbon fibers (CF) are used as one of the reinforcements for aluminium alloys, because they increase their stiffness and strength. Carbon fibershavebeen widely used as reinforcements in composites such as carbon fiber reinforced metals, plastics and ceramics due to their high specific strength, high electric and thermal conductivity, good self-lubrication and low expansion coefficient [5-6]. Also, carbon fibers increase the wear resistance and also reduce the friction coefficient of AMCs.

During the fabrication of carbon fiber reinforced aluminium matrix composites, poor wettability is one of the significant problems [7-8]. As reinforcements, the interfacial reaction between carbon fibers and matrix material makes it difficult to obtain carbon fiber reinforced materials with good interface bonding. Carbon fiber reacts with the molten aluminium and forms Al_4C3 [9-10]. This reaction damages the fibers severely and alters the

mechanical properties of the fiber and composites, respectively. Hence, by coating the fiber, it should be possible to avoid harmful reaction at the interface of the matrix and fiber,and also it must improve its wettability in the composite. Also, Magnesium (Mg) is a very good surfactant. Addition of Mg to the aluminium melt improves its wettability because of the lower surface tension of magnesium [11]. An optimum amount of Mg is required during the preparation of the composites.

The melting point of nickel is about 1455°C. By nickel plating, carbon fibers can be protected from oxidizing. Also, it can improve the wettability of carbon fibers. Electroless plating is one of the techniques used to apply nickel-coating on carbon fiber [12-13]. Also, it is essential to control the thickness of the nickel coating deposited over the carbon fiber. If the nickel deposited over the carbon fiber exceeds, specific limit nickel properties will dominate over carbon fiber. So, it is essential to maintain the thickness of the coating.

The fabrication of AMCs includes solid and liquid state processing methods. There are various methods to produce metal matrix composites using liquid state processing technique [14-16]. These methods include stir casting, pressure infiltration, and pressureless infiltration and squeeze casting. Al 7079 is a matrix metal, with zinc as the primary alloying element. Compared to many sheets of steel, it has good fatigue strength and is strong, but has average machinability. However, T6 heat treatment improves its machinability and also its hardness [17-19].

This work reports the implementation of the electroless deposition technique to coat nickel on carbon fibers. The microstructure of the coatings was examinedto confirm the uniformity of the coating and also to measure the thickness of the coating over the carbon fiber. Furthermore, the aluminium metal matrix reinforced with nickel coated carbon fibers was fabricated by stir casting technique, and the microstructure of the resulting composite was analysed. Finally, the cast composite was heat treated for different conditions and the hardness, wear, and fatigue property of the composite was evaluated.

2. EXPERIMENTAL PROCEDURE

2.1. Material Details

In the present investigation, Al 7079 is used as the matrix material. Zinc is the major alloying element in Al 7079. Addition of a small percentage of magnesium results in a better heat treatable alloy of high strength. The chemical composition of Al 7079 alloy is as shown in Table 1.

Table 1: Chemical Composition of Al7079

Composition	Zn	Mg	Cu	Fe	Si	Mn	Cr	Ti	Al
%	4.8	3.7	0.8	0.4	0.3	0.3	0.25	0.1	89.35

2.2. Reinforcement

The PAN (polyacrylonitrile) based continuous carbon fibersused as reinforcement. The long carbon fibersare separated from the spool and cut to a length of about 25cm and placed on manual printing press cutting machine. A feed of about 1mm and less has given for the cutting of the carbon fibers. Figure 1 shows continuous long carbon fibers.

Figure 1: PAN-Based Carbon Fibers

2.3. Coating of Carbon Fibers

About ½ kg of PAN-based short carbon fibers of about 1 to 1.5 mm length is taken. These fibers are coated by electroless technique. Electroless nickel coating procedure involves 3 main stages which are sensitization stage, activation stage and metallization stage [20]. Beforecoating, the short carbon fibers are initially cleaned with acetone solution for about 10 min to ensure that the fibers are free from any impurities. Then, it is rinsed with distilled water. Carbon fibers were placed on the oven and preheated to 200°C, so that the acetone solution evaporated and dried. During sensitization, the carbon fibers are dipped in a solution of 12 g/l of stannous chloride, under continuous stirring. The time for this process has been checked. Then, it is rinsed with distilled water. Carbon fibers were dried using filter paper and dipped in the 40 g/l of HCl. The fibers are again washed in distilled water and dried. Now, the fibers are dipped in an aqueous solution of 5 g/l of palladium chloride with continuous agitation. This process is called activation. The process leads to the formation of the palladium regions on the surface of the carbon fiber. The fibers are then dipped in 2.5 ml of HCl and rinsed with distilled water. During metallization, the fiberdipped in a solution containing 10 g/l of nickel sulphate which is a metallic ion source. The pH is maintained within 11 to 13 by adding NaOH pellets onto the solution. Then the fibers are cleaned with distilled water. The fibersthen dried at a temperature of about 70°C. Finally, the fibers are examined to determine the uniformity and thickness of the coating.

2.4. Specimen Preparation by Stir Casting Technique

One of the major problems in the preparation of the composite is to achieve proper dispersion of the reinforcement in the matrix to obtain a defect-free composite. Composite was prepared by mixing nickel coated carbon fiber with Al 7079 alloy by stir casting technique. Five samples were prepared by varying the percentage of reinforcement in the proportion of 0, 2, 4, 6 and 8 wt %. About 1.5 kg of Al 7079 alloy was pre-heated in a furnace for about 1 hour before melting it. Then, the Al 7079 alloy is melted in the furnace at about 720°C. The nickel coated carbon fiber was preheated for about 200°C in a furnace to remove the moisture content if any. Magnesium powder is added to the melt to reduce the surface tension of Al 7079 and to enhance the uniform mixing of the fiber in the melt. The stirring speed is maintained at about 500 RPM to create a vortex in the melt. The coated carbon fibersare then added to the melt, and the stirrer maintained at the same speed which will help the fiber spread wide over inside the crucible. Stirring continued until the reinforcement mixes well with the matrix. After proper mixing achieved,the melt is poured into the mould and allowed to solidify.

2.5. Heat Treatment of the Cast Specimen

Heat treatment improves the machinability and also the mechanical properties of Al 7079 MMCs. The casted composites are machined to required dimensions as per ASTM standards for various tests to be conducted. The machined sample is then subjected to a T6 heat treatment process. T6 heat treatment mainly involves three stages solutionising, quenching and artificial ageing. The specimens are initially heated to a temperature of 500 ± 10°C in a furnace for about 3 hours until the Al 7079 alloy solute elements completely dissolves in the Al robust solution. This process is known as solutionising. Then, the samples are removed from the furnace and water quenched immediately to prevent the precipitation of the solute elements. Finally, the quenched samples are reheated to 200°C for 2, 2.5, 3, 3.5, 4, 4.5, 5, 5.5 hours respectively, and hardness of the composite has evaluated. This process is known as artificial ageing.

2.6. Hardness Test

The hardness tests were carried out according to ASTM standards using Vickers hardness testing machine. The measurement of hardness value was taken at three different points on each of the test samples to obtain an average value of hardness. The test was conducted at room temperature (27°C).

2.7. Wear Test

Wear test was conducted to know the wear property of the material. The wear rates under the different conditions were calculated by conducting the test using the pin-on-disk machine. The disc rotates by the help of a D.C. motor in between 0-2000 RPM speed range with wear track diameter 50 mm-180 mm, which is capable of obtaining the sliding speed of 0 to 10 m/sec.

2.8. Fatigue Test

Fatigue is a condition, where a material fails due to the result of repeated loading (cyclic stresses) applied beneath the critical strength of the sample material. The fatigue characterization is carried out in a rotating beam fatigue testing machine. The specimen is subjected to four-point bending; the load is acting at four points equally in a fatigue testing machine. The specimen is rotated with the constant speed of 1500 RPM. Fatigue characterization is carried for various conditions such as 90, 80, 70, 60 50 40 and 30% of the ultimate strength of aluminium alloy matrix composite with different percentage of carbon fiber.

3. RESULTS AND DISCUSSION

3.1. Characterizationof Nickel-Coated Fiber

Figure 2: Photographs of (a) Un-Coated Carbon Fibers (b) Coated Carbon Fibers

Figure 2 shows the photographs of chopped uncoated and chopped nickel coated carbon fibers. Figure 3(a) shows the SEM image of uncoated carbon fibers surface. They have a circular section and a smooth surface. Figure 3(b) shows the coating obtained after 1 minute of metallization for which, a uniform coating obtained. Figure 3(c) and (d) shows the coating obtained after 2 minutes and 3 minutes of metallization, respectively. For longer times, undesired dendritic growth will take place.

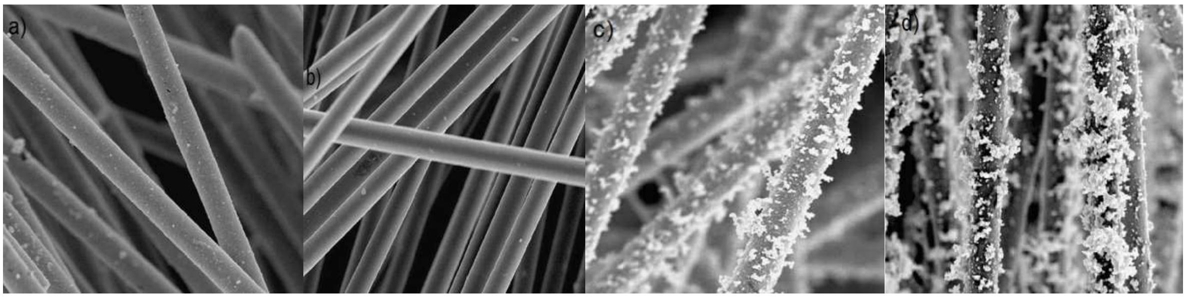

Figure 3: SEM Images of Carbon Fibers

Figure 4 shows a light microscopic image of the transverse section of the carbon fiber for 1 min of metallization time. Figure 5(a) shows the uniform coating thickness of 1.105µm over the carbon fiber for sensitization, activation and metallization time of 5, 5 and 1 minutes, respectively. Figure 5(b) shows the SEM image of uncoated carbon fibers which has the mean diameter of 6.22µm.

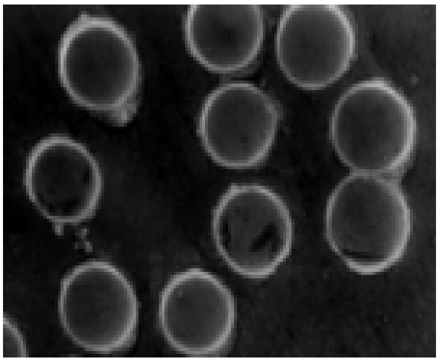

Figure 4: Microscopic Image of a Transverse Section of the Carbon Fiber

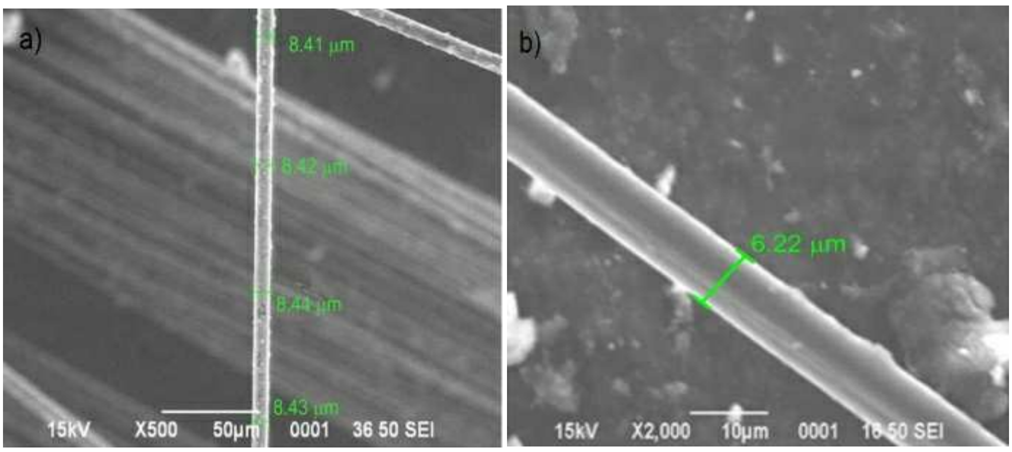

Figure 5: SEM Images Showing the Thickness of (a) Coated Carbon Fibers (b) Uncoated Carbon Fibers

3.2. Characterizationof the Composite Material Prepared

Fabrication of the composite done for 0, 2, 4, 6 and 8 weight percentages of carbon fiber, the microstructure of the specimens was then studied. Figure 6 shows the samples casted using stir casting process. Figure 7(a). Figure 7(b), Figure 7(c), Figure 7(d) and Figure 7(e) shows the microstructure of the casted specimen for 0, 2, 4, 6 and 8wt% of carbon fiber.

Figure 6: Casted Composite

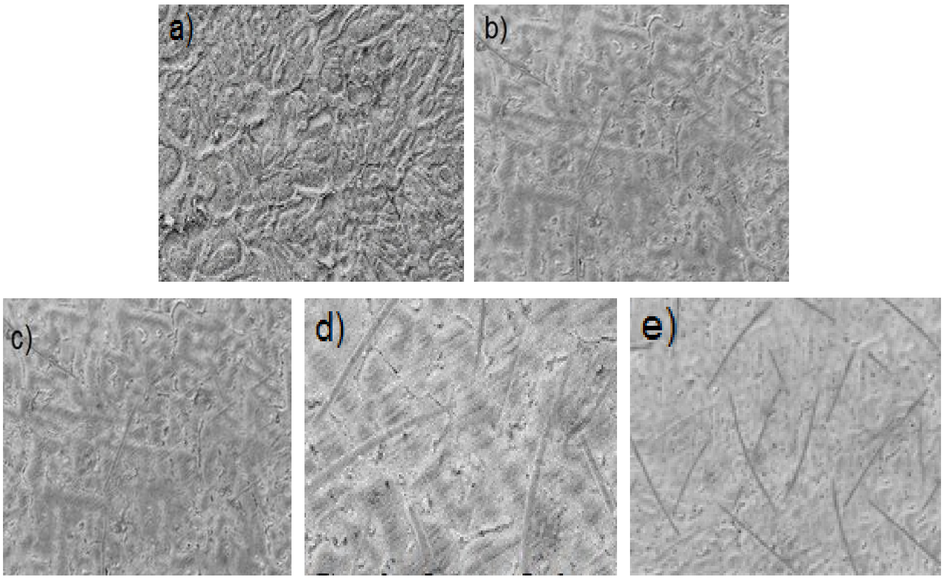

Figure 7: SEM Microstructure of the Casted Specimen for Different Wt% of Carbon Fiber

The microstructure of the casted specimens shows that the carbon fibersare uniformly distributed in the matrix. The random and uniform distribution of the carbon fiber shows the excellent wet tability of Al matrix with carbon fiber. Further,the casted specimens cut into 3 pieces along the length of the specimen, and the fiber distribution in the cast specimen was studied. It has been found that the microstructure at the top, bottom and middle of casting has displayed better uniformity of fiber distribution in the matrix material.

3.3. Hardness Evaluation for Heat Treated AMCs

The cast specimens are machined according to ASTM standards to determine the hardness of the heat-treated samples. The samples are then heat treated for different ageing time for the different percentage of reinforcement contents.

The hardness of the composite is very highly influenced by the ageing time. It increases with increasing time at the beginning of ageing, till it reaches a maximum value and then slightly decreases. The hardness increases due to the progressive formation of coherent precipitates; there is an increase of hardness, whereas due to the formation of non-coherent precipitates decreases its hardness with time. Table 2 shows mean hardness value (VHN) for different ageing time for different % of CF reinforcement. Figure 8 shows the mean hardness value (VHN) for different % of carbonfiber reinforcement.

Table 2: Mean Hardness Value (VHN) for Different % of CF Reinforcement

Time for Aging (hours)	Mean Hardness Value (VHN) for Different % of CF Reinforcement				
	0%	2%	4%	6%	8%
2	127	131	134	136	139
2.5	130	134	137	139	143
3	132	138	140	142	146
3.5	135	140	142	145	149
4	139	142	145	147	152
4.5	138	141	147	149	151
5	138	141	146	148	150
5.5	137	140	145	148	150

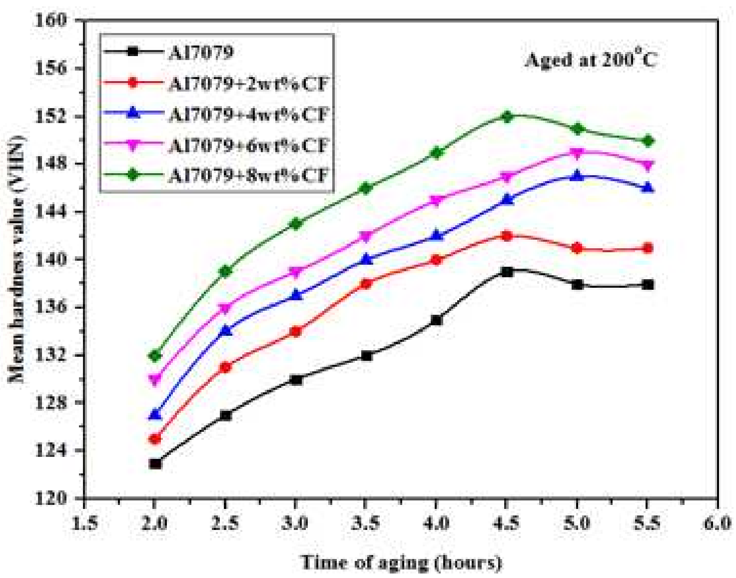

Figure 8: Mean Hardness Value (VHN) for Different % of CF Reinforcement

3.4. Wear Test for Different Sliding Distances

The effect of variation of sliding distance on the wear rate of nickel coated carbon fiber reinforced Al 7079 alloy was studied. In this case, the specimen rubbed against the disc at the constant speed of 1.5m/s and at constant load at 10 N. The diameter at which the specimen set is 57.3mm. The sliding distance is increased with fixed intervals, 1km, 2km, 3km and 4km the weight loss due to wear of Al 7079 composite increased too, and it is observed from the Figure 9 that wear rate increased with the sliding distance. It is also observedinFigure 5.9 that, when the percentage of carbon fiber increased, the wear rate was decreased considerably.

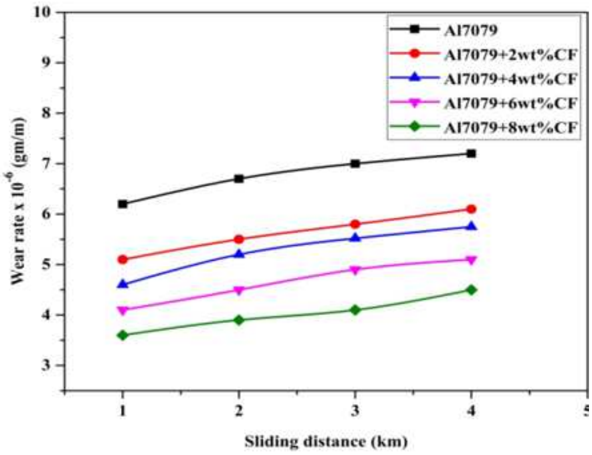

Figure 9: Wear Rate V/S Sliding Distance for Different Percentage of Carbon Fiber Reinforcement

3.5. Wear Test for Different Applied Loads on the Specimen

In this case, the specimen rubbed against the disc at the constant speed of 1.5m/s, and the distance covered by the specimen is 1km. The diameter at which the specimen is set is 57.3mm. The actual wear time is calculated as 11 min 11 sec per specimen. Figure 10 shows that with the increase of load and decrease in the percentage of carbon fiber, the average weight loss due to wear of Al 7079 composite increased under the same rotating speed.

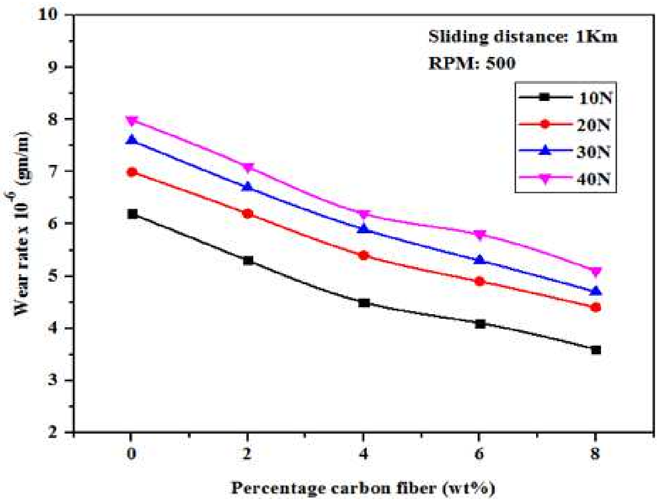

Figure 10: Wear Rate V/S Applied Load for Varying Percentage of Carbon Fiber in Al 7079 Composite

3.6. Fatigue Characterization

The experiment was conducted using 4 point rotating bending fatigue testing machine for different weight fractions of carbon fiber in the Al matrix composite. For low fatigue applications considering 2 machine cycles per day, the component is required to run for minimum 20 years in order to withstand total 150000 cycles. From the Figure 11, it is clear that Al alloy matrix composite with 8 wt% CF shows better fatigue strength compared to base alloy. The endurance strength has been increased by around 81 percent compared to base alloy.

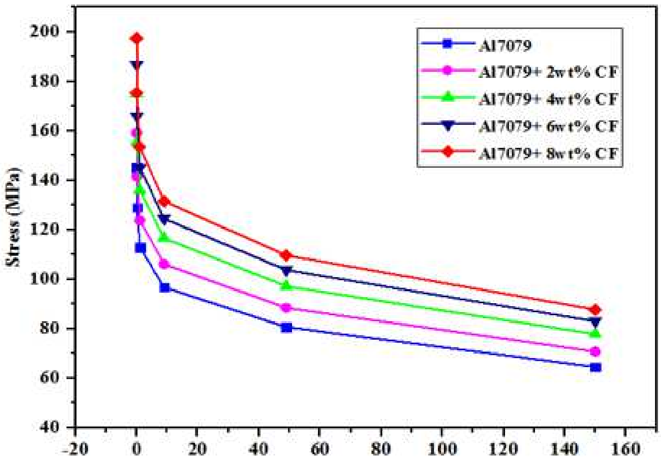

Figure 11: S-N Curve for Casted Al7079, 2, 4, 6 and 8 wt% CF Reinforced MMCs

4. CONCLUSIONS

The following conclusions are drawn from the study.

- SEM results confirmed that the carbon fiberswere coated with nickel by an electroless deposition technique. The nickel coated carbon fiber had a uniform thickness of 1.105µm throughout the length of the carbon fiber.
- The Nickel coating on carbon fibers improved the distribution of the fibers in the matrix. The microstructure of the casted specimens showed that the carbon fiberswere uniformly distributed in AMCs.
- The heat-treated composites exhibited better hardness,with the increase in artificial ageingtime, the hardness of the composite increased to a particular time, and a further increase in the ageing time reduced its hardness.
- Highest hardness was obtained for the heat treatment duration of 3 hours of solutionizing at 500°C and 4 hours of ageing at 200°C for 8% reinforcement of the composite.
- Wear rate was found to be decreasing with an increase in wt% of carbon fiber content, for the different conditions like a change in the sliding distance and change in applied load and 8 wt% of the carbon fiber, reinforcement wear rate was found to be minimum.
- The fatigue strength of the composite was found to increase with an increase in reinforcement content, and for 8 wt% of the carbon fiber as reinforcement, the fatigue strength was found to be maximum

REFERENCES

1. *Srinivas Rao, T. Prasad, M. Harish, "Evaluation of Mechanical Properties of Al 7075 – ZrO2 Metal Matrix Composite by using Stir Casting Technique", International Journal of Scientific Research Engineering & Technology, Volume 6, Issue 4, 2017, pp. 2278 – 0882.*
2. *G. Celebi Efe, M. Ipek, S. Zeytin, C. Bindal, "An Investigation of the Effect of SiC Particle Size on Cu–SiC Composites", Composites: Part B, vol. 43, 2012, pp. 1813–1822.*
3. *Neelimadevi C, "Mechanical Characterization of Aluminium Silicon Carbide Composite". International Journal of Applied Engineering Research Dindigul, Vol. 1, No 4, 2001, pp. 195-199.*

4. *Manish Narayan, M. K. Surappa and B. N. Pramila Bai, "Dry Sliding Wear of Al Alloy 2024~A1203 Particle Metal Matrix Composites", Journal of Wear, vol. 181, 1995, pp. 563-570.*

5. *M. A. Joseph, T. Shalu and E. Abhilash, "Development and Characterization of Liquid Carbon Fiber Reinforced Aluminium Matrix Composites", Journal of Materials Processing Technology, Vol.15, 2009, pp. 4809–4813.*

6. *Robert Singer and Franziskakachold, "Mechanical Properties of Carbon fiber Reinforced Aluminium Manufactured by High pressure Die Casting", vol. 25, 2016, pp. 3128–3133.*

7. *J. Rams, A. Urena, M.D. Escalera, M. Sanchez, "Electroless Nickel Coated Short Carbon Fibers in Aluminium Matrix Composites" Composites: Part A, vol. 38, 2005, pp. 1947–1956.*

8. *Zhongsheng Hua, Yihan Liu, Guangchun Yao, Lei Wang, Jia Ma, and Lisi Liang, "Preparation and Characterization of Nickel Coated Carbon Fibers by Electroplating", Journal of Materials Engineering and Performance, vol. 21, 2012, pp. 324–330.*

9. *Ziyuan Shi, Xuezhi Wang, Zhimin Ding, "The Study of Electroless Deposition of Nickel on Graphite Fibers", Applied Surface Science, vol. 140, 1999, pp. 106–110.*

10. *E. Hajjari, M. Divandari and A. Mirhabibi, "The Effect of Applied Pressure on Fracture Surface and Tensile Properties of Nickel Coated Continuous Carbon Fiber Reinforced Aluminium Composites Fabricated by Squeeze Casting", Materials and Design, Vol. 31, 2010, pp. 2381–2386.*

11. *Nithin Kumar, H. C. Chittappa, S. Ezhil Vannan, Vinayak Bhat, "Development of Aluminium-Nickel Coated Short Carbon Fiber Metal Matrix Compsite" Materials Today, 2017, pp. 1-8.*

12. *J. Rams, A. Urena, M. Escalera and M. Sanchez, Characterization of Interfacial Mechanical Properties in Carbon Fiber/Aluminium Matrix Composites by the Nano Indentation Technique, Composites Science and Technology, Vol. 65, 2005, pp. 2025–2038.*

13. *Lei Wang, Zhongsheng Hua, Yihan Liu, Guangchun Yao, Jia Ma, Lisi Liang., "Preparation and Characterization of Nickel-Coated Carbon Fibers by Electro-Plating", vol. 21, 2012, pp. 324-330.*

14. *G. Sozhamannan, S. Prabu and V. Venkatagalapathy, "Effect of Processing Parameters on Metal Matrix Composites: Stir Casting Process", Journal of Surface Engineering Materials and Advanced Technology, Vol. 2, 2012, pp. 11-15.*

15. *Grigoris E. Kiourtsidis, Stefanos M. Skolianos, "Wear Behaviour of Artificially Aged AA2024/40 SiCp Composites in Comparison With Conventionally Wear Resistant Ferrous Materials", Journal of Wear, vol. 253, 2002, pp. 946–956.*

16. *L. Lei, L. Weiwei, T. Yiping, S. Bin and H. Wenbin, "Friction and Wear Properties of Short Carbon Fiber Reinforced Aluminium Matrix Composites", Wear, Vol. 266, 2009, pp. 733–738.*

17. *Aziz, O. Q., & Taha, B. O. (2013). Mechanical Properties Of High Strength Concrete (Hsc) With And Without Chopped Carbon Fiber (CCF). International Journal of Civil Engineering (IJCE), 2(1), 1-12.*

18. *Veeravalli Ramakoteswara Raoa, Nallu Ramanaiah, Mohammed Moulana Mohiuddin Sarcar, "Mechanical and Tribological Properties of AA7075–TiC Metal Matrix Composites Under Heat Treated (T6) and Cast Conditions", j materres technol. 5(4), 2016, pp. 377–383.*

19. *Rong Chen, Akira Iwabuchi, Tomoharu Shimizu, "The Effect of a T6 Heat Treatment on the Fretting Wear of a SiC Particle-Reinforced A356 Aluminum Alloy Matrix Composite", Wear 238, 2000, pp. 110–119.*

20. *KM, A. F., & Varghese, S. (2014). Behavioural study of steel fiber and polypropylene fiber reinforced concrete. Int. J. Res. Eng. Technol., 2(10).*

21. *E. Subba Rao and N. Ramanaiah, "Influence of Heat Treatment on Mechanical and Corrosion Properties of Aluminium Metal Matrix composites (AA 6061 reinforced with MoS2)", Materials Today: Proceedings 4, 2017, pp. 11270–11278.*
22. *S. E. Vannan, S.P. Vizhian, R. Karthigeyan, G. Ranganath, "Effect of Coating Parameters on Coating Morphology of Basal Short Fiber for Preparation of Al/Basalt Metal Matrix Composites", International Journal of Science Research". Vol. 1, 2013, pp. 232-236.*